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RESEARCH ARTICLE

New records of mammals of the Coffee Region, Central Andes of Colombia using citizen science

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Abstract

The Coffee Region of Colombia is one of the most representative areas of the country due to its cultural appeal. 200 of the 528 mammal species in the country occur in this region. Pre-existing knowledge about the group in this region has been obtained through indirect and direct sampling methods. We present new records of mammals of the "Reserva Forestal Protectora Bosques de la Central Hidroeléctrica de Caldas (CHEC)", located in the Coffee Region, based on vouchered citizen science records. To accomplish this, we held training workshops on the relevance of information provided by non-invasive vouchers for mammal collections that include bone remains, hairs, skin and other signs that can be found incidentally in the field by park rangers and other staff of the Reserve. In addition, we included photographic and video records of mammals taken by park rangers before and after the training workshops. We added vouchers obtained by the park rangers to the biological collection of the Natural History Museum of the Universidad de Caldas (MHN-UCa). Using this method, we obtained records of 34 mammalian species belonging to 20 families and 11 orders. We highlight the obtention of museum preserved vouchers of the Northern Naked-tailed Armadillo, *Cabassous centralis* (Miller 1899), and the Cauca Slender Opossum, *Marmosops caucae* (Thomas 1900), that had limited samples in national collections or had not been previously collected in the study area. With this work, a contribution network with the CHEC reserve staff was established, promoting the inclusion of these agents in the development of scientific research, and showing the relevance of collaborative science in assisting with filling information gaps about medium and large mammals.

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PENSOFT

Keywords
Andes, Colombia, conservation, Mammalia, non-invasive records, protected areas, tracks

Introduction

Colombia is home to an impressive diversity of mammals with over 528 species (Ramírez-Chaves et al. 2019). Most knowledge on this biodiversity of mammals comes from information provided by natural history museums (e.g., Navarro et al. 2003; Solari et al. 2013; Castaño et al. 2017; Ramírez-Chaves et al. 2018). Despite the elevated number of mammal species of the country, there are still information gaps on different topics such as natural history, biogeography, ecology, anatomy, and systematics (see Andrade-Ponce et al. 2016, for information on some charismatic families within Carnivora).

For the Colombian Coffee Region (departments of Caldas, Risaralda, and Quindío), one of the most emblematic areas of the Andean Region of the country, 200 species of mammals have been reported, including bats (93 species), rodents (49 species), marsupials (14 species), rabbits (two species), and other medium and large mammals (Orjuela and Jiménez 2004; Sánchez et al. 2004; Perez-Torres and Cortes-Delgado 2009; Castaño Salazar 2012; Parra-Colorado et al. 2014; Garcés Restrepo et al. 2016; Castaño et al. 2017; Vásquez-Palacios et al. 2019). Some of these records were collected through interviews with the local communities and non-invasive techniques such as photographs, bones, fur, and other signs (Orjuela and Jiménez 2004; Parra-Colorado et al. 2014), and/or by using vouchers housed in local biological collections (Castaño et al. 2003; Sánchez et al. 2004; Castaño Salazar 2012; Marín et al. 2012; Escobar-Lasso and Guzmán-Hernández 2014; Mantilla-Meluk et al. 2014; Escobar-Lasso and Gil-Fernandez 2019). Some of the historical records of mammals in the Coffee Region include charismatic or endangered species such as the Jaguar, *Panthera onca*, in the Department of Caldas, the last report of which dates back to 1998 (Escobar-Lasso et al. 2014), the Mountain Tapir, *Tapirus pinchaque*, and the Neotropical Otter, *Lontra longicaudis*, which are listed as among the country's threatened category (Castaño Salazar 2012).

Despite the importance of this biological information, the representation of medium and large mammals in collections and museums on a regional level is still scarce (Castaño-Ramírez and Ramírez-Chaves 2018), since, due to the low population densities of these species, scientific collection is not an option (Patterson 2002). In addition, the inventories of medium and large mammals in the Coffee Region are still incomplete, and it has been suggested that to fill the information gaps complementary sampling techniques should be used (Sánchez et al. 2004). To assist with filling these gaps, the use of citizen science, defined as the incorporation of non-professional scientists in projects that collect or analyze

reliable information to be used by scientists for decision making (Haklay 2013; McKinley et al. 2017) is an alternative worth exploring. Citizen science is crucial to support data collection and even to monitor population changes over time, allowing researchers not only to get more complete data, but also to promote conservation by divulgating both the justification for, and the results of, the research (Bonney et al. 2009; Dickinson et al. 2012). To date, the implementation of citizen science data collection has proven to be a helpful way to perform conservation-related works (e.g., Sterrett et al. 2019; Yang et al. 2019; Earp and Liconti 2020; Bonnet-Leburn et al. 2020).

In Colombia, citizen science has provided valuable information for the study of rare mammal species (Gerstner et al. 2018; De Roux et al. 2019; Ramírez-Chaves et al. 2020a, b) especially in the Andean Region, which is considered a high global priority for biodiversity conservation (Myers 1998), and one of the most threatened regions of the country as it hosts most of the human population (Quintero-Gallego et al. 2018), and its economic activity relies on the industrial sector and extensive agriculture (Armenteras et al. 2003; Rodríguez Eraso et al. 2013). In these studies, however, the collection of physical vouchers by the local community that might be useful for other studies (e.g., taxonomy, systematics) was not considered, limiting the research scope only to distribution and conservation updates. Considering this, we present new records of mammals in three sites of a protected area placed in the departments of Caldas and Risaralda in the Coffee Region of the Central Andes of Colombia, based on vouchered (photographs and specimens found dead in the field) citizen science records.

Materials and methods

Study area

The study was carried out in the departments of Caldas and Risaralda, Colombia (Fig. 1), in three particular areas; two of them are connected in the upper part with the National Natural Park Los Nevados, that protects high Andean forest and sub-páramo ecosystems: (i) Reserva Forestal Protectora Bosques de la Central Hidroeléctrica de Caldas (CHEC), (ii) conservation area of CHEC and (iii) Bosques de La Esmeralda. The Reserva Forestal Protectora Bosques de la CHEC (04°52"N, 75°24"W) is located in the jurisdiction of the municipalities of Manizales and Villamaría, Department of Caldas (Roncancio and Estévez 2007), with an extension of approximately 3,893 ha and an elevational range between 2,400 and 4,000 m. (Ramírez-Mejía and Sánchez 2015). The conservation area of the CHEC Los Alpes (04°48"N, 75°31"W), is situated in the jurisdiction of the municipality of Santa Rosa de Cabal, Department of Risaralda, Colombia, with an extension of 499.2 ha and an elevational range between 2,900 and 3,800 m. The Bosques de La Esmeralda

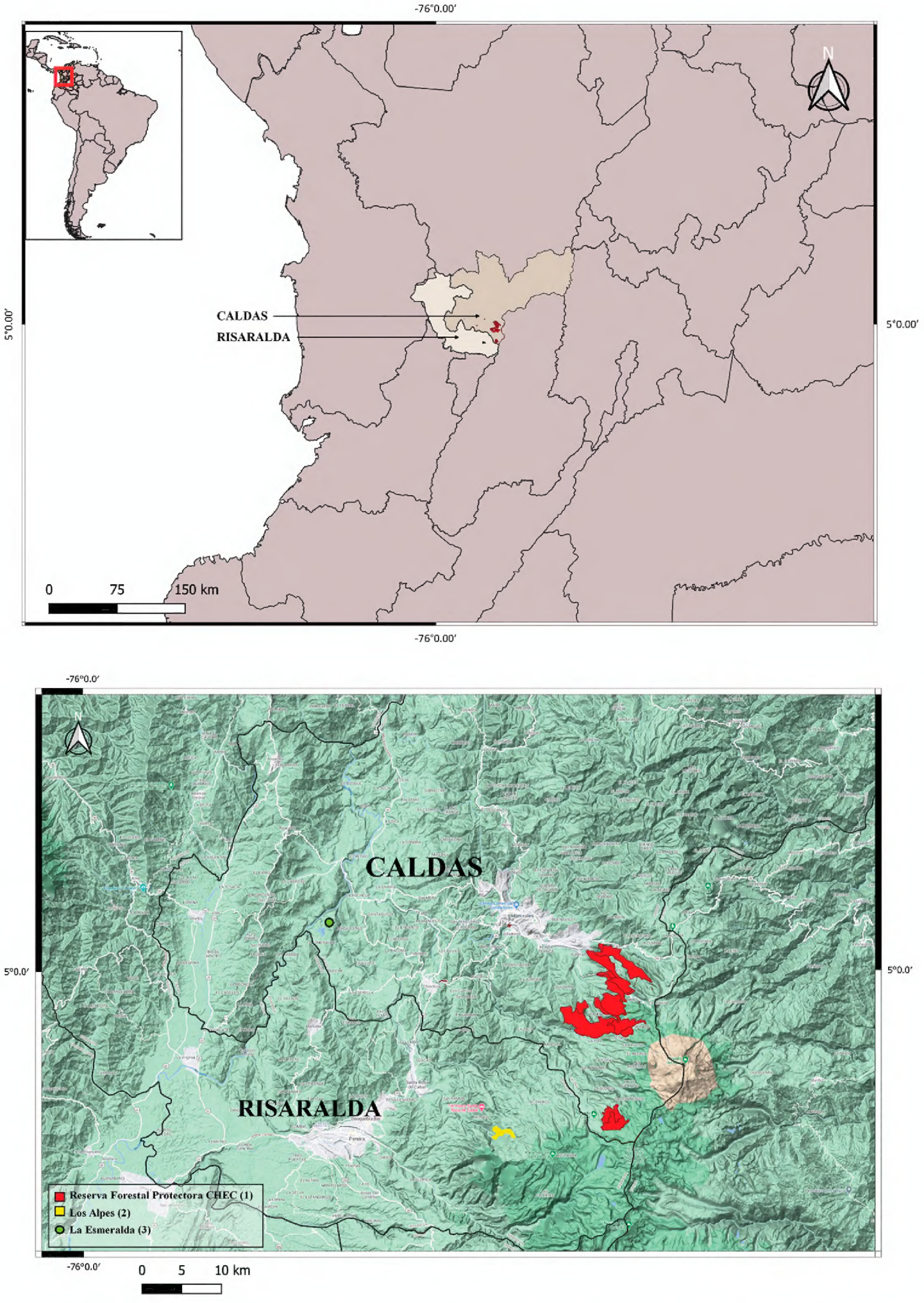

Figure 1. Study area in the Coffee Region, departments of Caldas and Risaralda, Central Andes of Colombia. Top: Political boundaries of the Departments of Caldas and Risaralda, Colombia. Bottom: Details of the Andean and inter-Andean landscape in both departments.

(05°03"N, 75°44"W) is located close to the Cauca River in jurisdiction of the municipality of Chinchiná, Department of Caldas, with an extension of approximately 40 ha, and an elevational range between 825 and 1,025 m (Castaño-Villa et al. 2008; Sanín et al. 2014). All three areas are located on the western slope of the Central Cordillera of Colombia, and immersed in tropical rainforest, Andean forest, Andean high forest, sub-páramo and páramo life zones.

Data collection

To obtain citizen science records, we conducted three animal preservation training workshops between 2018 and 2019 for the CHEC conservation area rangers, CORPOCALDAS (Autonomous Regional Corporation) staff, and park rangers of Los Nevados National Natural Park. The workshops aimed to instruct them on the relevance of preservation of biological evidence (vouchers) for research studies. During the training sessions we stressed the proper handling of the samples (handling and maintenance of dead specimens), and the associated information to be collected with the specimen. An additional lecture took place in the facilities of the Museo de Historia Natural de la Universidad de Caldas (MHN-UCa), where a total of 21 park rangers had the opportunity to visit the mammals' collection and the preserved vouchers.

Biological samples and records

Citizen science vouchers (photographs and whole specimens or bone remains) were collected circumstantially by those in charge of all three study sites, and buffer zones. The samples found were handled with gloves and placed in plastic bags to be taken to the Natural History laboratory of the MHN-UCa where the preservation and identification took place. In the collection, the complete specimens were frozen, while the bone remains were washed and then dried in a dehydration oven. For the complete specimens, once the condition was evaluated, they were prepared as skin, skull and skeleton, or preserved in fluid 70% alcohol (Nagorsen and Peterson 1980), and tissue samples were preserved in 96% alcohol (Kilpatrick 2002) for future molecular studies. When possible, we took external standard measures used in the study of mammals (Nagorsen and Peterson 1980), and cranial measurements for identification (Cerqueira and Lemos 2000; Voss et al. 2004; Hayssen 2011; Voss 2011; Quiroga-Carmona and Molinari 2012; Marín et al. 2012). Furthermore, we obtained photo-vouchers and videos donated by local people and CHEC staff taken at the study area between 2014 and 2019 pre- and post-workshops. We used the photographs to complete the information on the mammal species of the study area, a technique that has been also implemented in other studies to obtain additional data on mammals from Colombia (Ramírez-Chaves et al. 2020a, 2020b; Torres-Martínez et al. 2020).

Table 1. Mammal species recorded at three private areas located on the western slope of the Central Cordillera of Colombia: Reserva Forestal Protectora CHEC (1), conservation area of CHEC Los Alpes (2) and Bosques de La Esmeralda (3). Species supported by vouchers obtained as donations through citizen science to the MHN-UCa include the number and the catalogue code. Previous vouchers include the number of specimens housed at the MHN-UCa-M before this study took place. The condition of the photographed specimens between 2014 and 2019 is reported.

Taxon	Previous museum vouchers	Sites	New museum vouchers	Photo-vouchers (2014–2019)
Didelphimorphia				
Didelphis marsupialis Linnaeus, 1758	22	1, 2, 3	1 (MHN-UCa-M 1924)	2 alive
Didelphis pernigra J.A. Allen, 1900	–	2	–	1 alive
Caluromys derbianus (Waterhouse, 1841)	–	2	–	1 alive
Marmosops caucae (Thomas, 1900)	6	1	1 MHN-UCa-M 1759	
Cingulata				
Cabassous centralis (Miller, 1899)	2	1	1 MHN-UCa-M 2091	1 alive
Dasypus novemcinctus Linnaeus, 1758	17	1, 3	2 MHN-UCa-M 2083–2084	3 alive, 2 corpses
Pilosa				
Choloepus hoffmanni Peters, 1858	9	1, 2, 3	2 MHN-UCa-M 1927–1928	7 alive (including 1 cub), 1 hair remains
Tamandua mexicana (Saussure, 1860)	–	2		1 alive, 1 corpse
Eulipotyphla				
Cryptotis colombianus Woodman and Timm, 1993	67	1	2 MHN-UCa-M 1925–1926	2 corpses
Chiropter				
Saccopteryx bilineata (Temminck, 1838)	–	3	–	1 alive
Artibeus lituratus (Olfers, 1818)	63	1	1 MHN-UCa-M 1930	
Platyrrhinus cf. *helleri* (Peters, 1866)	–	3	–	1 alive
Glossophaga cf. *soricina* (Pallas, 1766)	–	2	–	1 alive
Eptesicus fuscus miradorensis H. Allen,1866	–	1	–	1 corpse
Carnivora				
Leopardus tigrinus (Schreber, 1775)	–	3	–	1 cub alive
Leopardus wiedii (Schinz, 1821)	–	1	–	1 alive
Cerdocyon thous (Linnaeus, 1766)	10	1, 2, 3	1 MHN-UCa-M 1803	1 alive, 1 skull
Lontra longicaudis (Olfers, 1818)	–	3	–	4 alive
Eira barbara (Smith, 1842)	–	1, 3	–	2 alive
Mustela frenata (Lichtenstein, 1831)	–	1	–	1 alive
Nasua nasua (Linnaeus, 1766)	–	1, 2, 3	–	3 alive, 1 corpse
Nasuella olivacea (Gray, 1865)	7	1, 2	1 MHN-UCa-M 2033	5 alive (including 4 cubs), 2 bone and hair remains
Potos flavus (Schreber, 1774)	–	2, 3	–	4 alive
Procyon cancrivorus (Cuvier, 1728)	8	2	1 MHN-UCa-M 1929	
Perissodactyla				
Tapirus pinchaque (Roulin, 1829)	–	1	–	2 alive
Artiodactyla				
Mazama rufina (Pucheran, 1851)	1	1	3 MHN-UCa-M 2032, MHN-UCa-M 2049, MHN-UCa-M 2777	1 alive
Primates				
Aotus lemurinus (I. Geoffroy, 1843)	–	3	–	1 alive, 1 corpse
Alouatta seniculus Linnaeus, 1766	–	3	–	1 alive
Rodentia				
Syntheosciurus granatensis (Humboldt, 1811)	–	1, 2	–	6 alive
Cuniculus taczanowskii (Stolzmann, 1865)	7	1	2 MHN-UCa-M 1931–1932	2 skulls
Cuniculus paca (Linnaeus, 1766)	12	1	1 MHN-UCa-M 2774	
Coendou rufescens (Gray, 1865)	10	1, 2, 3	2 MHN-UCa-M 1933–1935	2 alive
Dasyprocta punctata Gray, 1842	–	3	–	1 alive
Lagomorpha				
Sylvilagus cf. *salentus* (J.A. Allen, 1913)	7	1	6 MHN-UCa-M 1936–1941	1 alive, 1 bone remains

Results

During 2018 and 2019 a total of 28 mammal vouchers (specimens) of 15 species, 14 genera and 11 families were recovered by the CHEC staff in the study area. The most recurrent type of sample was bone remains, followed by skulls and recent corpses (Table 1). Despite the quality of some of the samples, the diagnostic characters for specific identification were preserved.

The Cottontail Rabbit (*Sylvilagus* cf. *salentus*) and the Stump-tailed Porcupine (*Coendou rufescens*) presented the highest number of records with six and three, respectively. In addition, vouchers of four species of carnivores, two of marsupials, three of the Dwarf Red Brocket Deer (*Mazama rufina*), among others, were recovered (Table 1). Although the emphasis was on samples from medium and large sized mammals, we also obtained three samples of small mammals, two Colombian Small-eared Shrews (*Cryptotis colombianus*), and one Great Fruit-eating Bat (*Artibeus lituratus*).

The months with the highest number of records were February and May 2018. The locality with the highest number of records was the Romeral II sector located in the town of Termales in the municipality of Villamaria, Caldas with eight records; followed by Gallinazo in Villamaria and El Chuzo in the municipality of Santa Rosa de Cabal, Risaralda with three records each.

From the analyses of photo-vouchers and videos, we obtained 80 records that allowed us to identify 30 species of 27 genera and 11 orders (Table 1). The photographs included samples such as bones, fur, road kill, and alive animals (Figs 2, 3). Unlike the physical vouchers, these records were obtained throughout the whole year. August and January were the months with the highest number of records while 2015 and 2016 were the years with the highest number. With all the information sources, the total list of mammals registered in the study area amounted to 34 species, belonging to 31 genera, 21 families, and eleven orders. According to the IUCN Red List of Threatened Species (IUCN 2020), the records included Endangered species such as the Mountain Tapir (*Tapirus pinchaque*), and three Vulnerable species, the Colombian Night Monkey (*Aotus lemurinus*), the Dwarf Red Brocket Deer (*M. rufina*), and the Oncilla (*Leopardus tigrinus*) (Table 1).

Based on the records, we recognized several natural history interactions, such as the presence of juvenile individuals of Mountain Coati *N. olivacea*, Oncilla *L. tigrinus* (Fig. 2), and the Hoffmann's Two-toed Sloth *Choloepus hoffmanni* (Fig. 3), photographed on July 3rd 2015, August 2nd 2016, and December 10th 2019, respectively, showing that reproductive periods are occurring throughout the year in the study area. With this information, we also documented the presence of sympatric coati species such as the South American Coati, *Nasua nasua*, and the Mountain Coati, *Nasuella olivacea* (Fig. 3), and the killing of Dwarf Brocket Deer (*M. rufina*) by either a domestic dog (one event) or by cougars (two events) (Fig. 4).

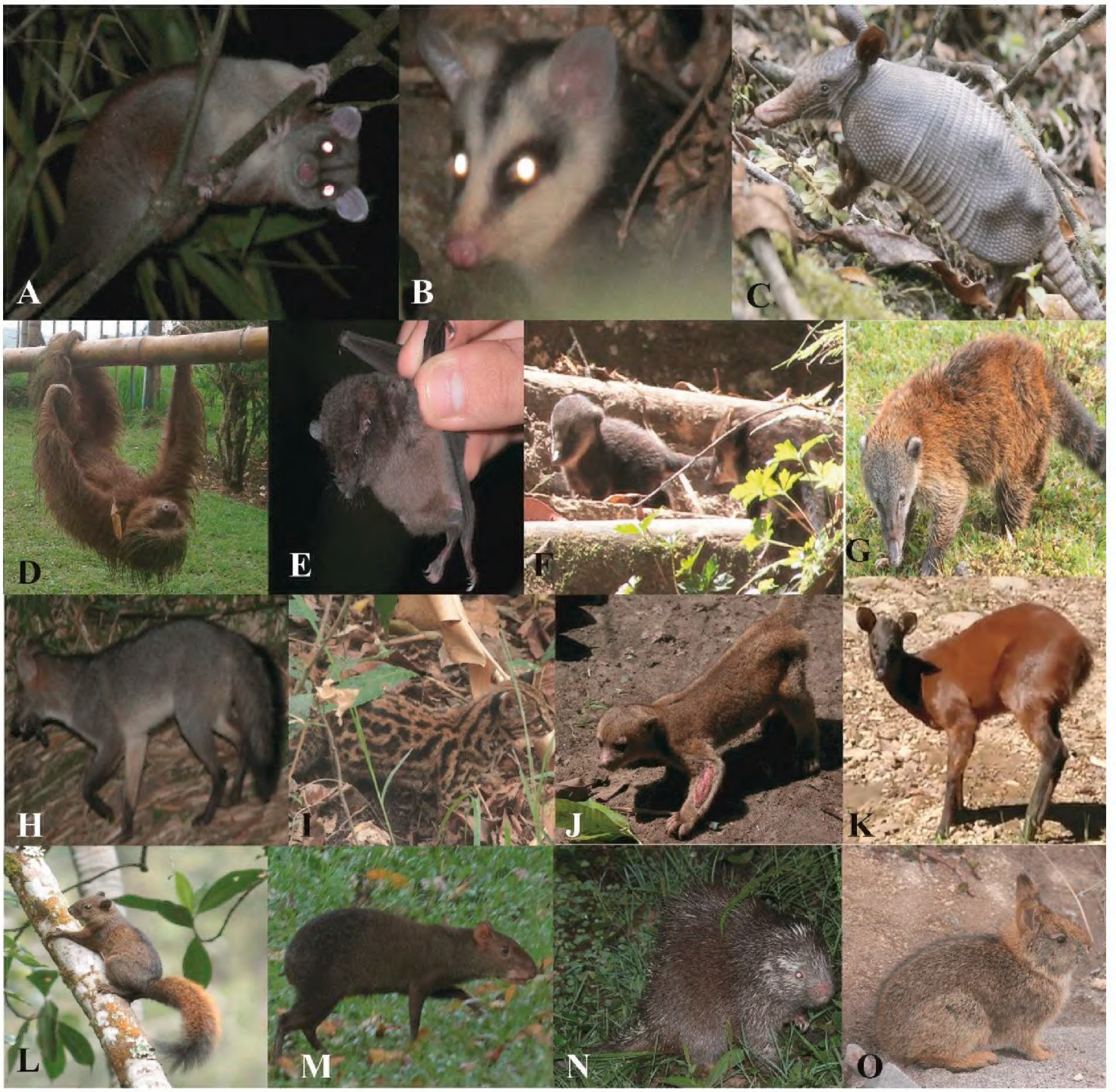

Figure 2. Alive specimens photographed by the local people between 2014 and 2016 in private areas located on the Central Cordillera of Colombia. None of the animals were kept captive. **A.** *Caluromys derbianus.* **B.** *Didelphis pernigra*, **C.** *Dasypus novemcinctus*, **D.** *Choloepus hoffmanni*, **E.** *Glossophaga* cf. *soricina*, **F.** *Nasuella olivacea*, **G.** *Nasua nasua*, **H.** *Cerdocyon thous*, **I.** Cub of *Leopardus tigrinus*, **J.** *Potos flavus* with scabies, **K.** *Mazama rufina*, **L.** *Syntheosciurus granatensis*, **M.** *Dasyprocta punctata*, **N.** *Coendou rufescens*, **O.** *Sylvilagus* cf. *salentus.*

Discussion

Our results contribute to our knowledge of the distribution of different mammal species in the Coffee Region (including threatened species), and to the strengthening of biological collections. Although most of the species recorded had been previously confirmed for the Department of Caldas and Risaralda (Castaño Salazar 2012; Castaño et al. 2017), there were new records at a regional level. For example, a previous study conducted at the CHEC Natural Reserve based on camera-trapping (Ramírez-Mejía and Sánchez 2015) did not record the Common Opossum (*Didel-*

Figure 3. Alive specimens photographed by the local people between 2017 and 2019 in private areas located on the Central Cordillera of Colombia. **A.** *Cabassous centralis*, **B.** An adult female and a juvenile of *Choloepus hoffmanni*, **C.** Adult *Choloepus hoffmanni*, **D.** *Tamandua mexicana*, **E.** *Eptesicus fuscus miradorensis*, **F.** *Leopardus wiedii*, **G.** *Eira barbara*, **H.** *Potos flavus*, **I.** *Tapirus pinchaque.*

phis marsupialis), the Cauca Slender Opossum (*M. caucae*), the Hoffman's Two-toed Sloth (*C. hoffmanni*), the Crab-eating Raccoon (*Procyon cancrivorus*), and the Cottontail Rabbit (*S.* cf. *salentus*). For the latter, its presence had been recorded in the nearby Río Blanco reserve (namely *Sylvilagus brasiliensis*) but not at the CHEC Reserve (Ramírez-Mejía and Sánchez 2015). The vouchers obtained were also useful to explore the morphological characters of some taxa. For example, the specimen of *M. caucae* (MHN-UCa-M-1759), exhibited some characters that did not fit the re-

Figure 4. Signs of a Dwarf Red Brocket Deer (*Mazama rufina*) killed by a cougar (*Puma concolor*) in Bosques de la CHEC, Central Cordillera of Colombia, found on August 2nd, 2019 by H. Ramírez-Chaves. **A.** Mandible of the red brocket deer, **B.** Footprint of the cougar, **C.** Front leg of the deer. Deer's remains were deposited in the mammal's collection as MHN-UCa-M 2777.

description of the species (Díaz-N. et al. 2011; Díaz-Nieto and Voss 2016), such as the number of antebrachial vibrissae, with two instead of one. However, the specimen exhibited most of the diagnostic characters, such as the absence of cuspids on its upper incisors and the connections of the pads of the left hind foot (Díaz-N. et al. 2011). In addition, the record of *M. caucae* is the first confirmed for the study area, despite the species being previously recorded in the Department of Risaralda (Castaño et al. 2017).

Similarly, the two specimens of *Cryptotis*, MHN-UCa-M 1925-1926, mostly matched the characters of *Cryptotis colombianus* including small to medium size (head and body length: 61.72, 68.75 mm), short tail (33.11, 32.92 mm), length between third upper molars (6.42, 5.48 mm respectively). *C. colombianus* has been previously recorded for the municipalities of Manizales and Villamaría (Escobar-Lasso et al. 2013), and our records contribute towards showing the current presence of the species in the

study area. For both *M. caucae* and *C. colombianus*, geographic variation should be explored using additional samples from other localities of Colombia. Furthermore, the addition of samples from some groups such as rabbits (*Sylvilagus*) is relevant due the fact that the skull of the holotype of *S. salentus* is broken (Ruedas et al. 2019) limiting taxonomic comparisons. The specimens of *Sylvilagus* collected in this study (MHN-UCa-M 1936–1941), match the characters of *S. salentus* and may help to clarify basic aspects of the genus taxonomy which has been studied recently for the Central Cordillera of Colombia (see Diersing and Wilson 2017; Ruedas et al. 2019). The presence of two coati species is also interesting due to that sympatry only recently being reported in Colombia (González-Maya et al. 2015), and Peru (Mena and Yagui 2019).

Similar strategies of collecting non-invasive information about mammals (e.g., interviews, and the search for tracks and signs), but ones that did not lead to the strengthening of biological collections, have been historically used to study medium and large mammals in Colombia (Guzmán-Lenis and Camargo-Sanabria 2004; Sánchez et al. 2004; García-Herrera et al. 2015; Alfaro and Quesada 2016). We recorded almost the same number of species previously identified in the study area using other sampling techniques; however, the sampling effort among our and previous studies, is not comparable. Based on these, we suggest that using citizen science to study the local fauna, as it has been applied to charismatic mammalian species (Gerstner et al. 2018), should be considered for long-term monitoring plans of the local biodiversity in the country. With all these records, to date a total of 37 mammal species (34 in the present study) have been recorded in Reserva Forestal Protectora Bosques de la CHEC and Los Alpes (Roncancio and Estévez 2007; Ramírez-Mejía and Sánchez 2015; Castaño et al. 2017). We expect a higher mammal diversity at La Esmeralda, especially for small mammals such as bats, rodents, and marsupials, due to the lowest elevational range.

Finally, the training workshops allowed for scientific dissemination and established contact networks with the park rangers of the reserve, and also enabled collaboration between academic institutions and local stakeholders. This also helps to fulfill our objective of avoiding discrediting or ignoring the assistance of those who are exposed daily to this information. Opening the doors of science to agents outside this field allows for the collection of information that could only be acquired with a high sampling effort (Bonney et al. 2009). In this way, we can contribute to the biodiversity knowledge without disturbing the environment, and to the collection of valuable information that can later be deposited in educational centers such as natural history museums. Instructing, connecting and socializing this type of work with the community will help to fill information gaps and increase the knowledge of poorly studied animal groups.

Conclusion

Communication with people living nearby the protected area (Bosques de la CHEC), and with local employees and park rangers in order to collect key information for

mammalogical studies, showed positive results with 34 species reported for the study area. The vouchers obtained by using citizen science allowed us to compile data for a period of six years and to update the mammal list of the study area. Besides the relevance of citizen science records for distribution and conservation studies, the preservation of museum vouchers is recommended due to the relevance of these collections to address additional research questions including morphological and genetic variation, systematics and taxonomy, among others.

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